Right Whale Diving and Foraging Behavior in the Southwestern Gulf of Maine

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LONG-TERM GOALS

Mitigation of a variety of anthropogenic threats to endangered baleen whales depends on information about how the whales use the water column. For example, reducing ship strike risk requires an understanding of how much time whales spend at the surface, and mitigating fishing gear entanglements by ground lines requires an understanding of how often and why whales might dive near the bottom. My long-term goal is to characterize baleen whale foraging behavior by studying diving behavior with respect to vertical/horizontal prey distribution, physical water column features (e.g., mixed layer, stratification, turbulence), and the acoustic environment. This approach will allow me to characterize not only where in the water column the whales feed, but also where the prey are located, why the prey are organized as they are, and how the whales respond to variability in both prey distribution and conspecific acoustic behavior. By using this same approach to study several baleen whale species, comparisons between species will ultimately be possible to address fundamental questions about foraging ecology (e.g., variability in foraging strategy induced by morphological constraints and/or prey species/behavior) as well as about differential rates of interaction with human activities.

OBJECTIVES

The seriously endangered North Atlantic right whale is particularly vulnerable to ship strikes and fishing gear entanglements, and there is an urgent need for information about how right whales use the water column to develop strategies to mitigate these anthropogenic threats. Moreover, the right whale sits atop a relatively simple food chain consisting only of phytoplankton, copepods, and whales that can serve as a convenient model to study trophic interactions in the marine environment because both predator and prey can be monitored with available technologies (e.g., animal-mounted archival tags, video plankton recorder). In 2005-2007, we conducted research on the diving and foraging behavior of North Atlantic right whales in the Great South Channel, but in light of the variability in diving behavior that we observed, the sample size obtained during those years was insufficient to completely characterize the whales' behavior. The objective of this project was to extend our observations of right whale diving and foraging behavior by simultaneously collecting behavioral, oceanographic, and prey observations to fully characterize (1) the behavior of the tagged whales, (2) their response to cues from

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the physical environment and the prey field, and (3) the physical and biological processes that influence the vertical distribution of copepods.

APPROACH

Tagging, tracking, and sampling around right whales was accomplished with two vessels: an oceanographic vessel and a small, rigid-hulled inflatable boat (RHIB). After right whales were encountered, the RHIB was deployed from the oceanographic vessel (Figure 1a). Right whales were approached in the RHIB and suction-cup mounted archival tags were attached to the whales from this boat using a 9 m pole (Figure 1b,c). The tag consists of a time-depth recorder, pitch and roll sensors, a VHF radio transmitter, and a high-frequency acoustic transmitter. After successful deployment, the tagged whale was actively tracked via a high-frequency acoustic transmitter incorporated in the tag using an acoustic receiver and a hand-held directional hydrophone carried in the tagging boat. The tagging boat remained near the tagged whale at all times to collect identification photographs, behavioral information, fecal samples (if available), and to record the whale's surface locations. Upon resurfacing after each long dive, the whale's exact resurfacing position is recorded by the tagging boat using a global positioning system (GPS) receiver. This position is then relayed via radio to the oceanographic vessel and the ship moved to that position to deploy our vertical profiling instrument package (Figure 1d), which consists of a conductivity-temperature-depth (CTD) instrument, chlorophyll fluorometer, optical plankton counter, and video plankton recorder. Tracking and sampling with the instrument package continued until the tag detached from the whale, floated to the surface, and was recovered. The tag incorporated a corrosive release mechanism that allowed detachment after 1-3 hours.

WORK COMPLETED

In 2009, we worked from the WHOI coastal research vessel *Tioga* in the Great South Channel of the southwestern Gulf of Maine between Cape Cod and Georges Bank. During that research, we tagged 11 right whales, but not one tag remained attached for more than 1 hour. We had the opportunity to return to the Great South Channel during the spring of 2010 on the NOAA Ship *Delaware II* with the NOAA Northeast Fisheries Science Center. Because one of the hypotheses for the poor attachment success in 2009 was an overly flexible suction cup, we made modifications to the cup to stiffen it prior to the 2010 cruise. We also brought dermal-attachment tags in case the suction cups failed, but we fortunately did not need to use them. Fieldwork was conducted aboard the NOAA Ship *Delaware II* from May 3-20, 2010, during which we spent 7 days on the water in the tagging boat. Preliminary analyses of the tagging data were completed and are described below.

RESULTS

Weather conditions allowed deployment of the tagging RHIB on 7 of the 18 days of the cruise. We successfully tagged 14 North Atlantic right whales during those 7 days (Table 1). Of the 14 tagging events, 7 tags remained attached for more than 1 hour (Table 1, Figure 2). A total of 51 casts were completed with our vertical profiling instrument package in proximity to the tagged whales. We observed almost exclusive near-surface feeding (Figure 3) in some of the largest feeding aggregations of both right and sei whales I have ever seen. Only the suction-cup tags were used during the cruise; while we were prepared to use a new dermal attachment tag, our success with stiffened suction cups made this unnecessary. It appears that stiffening the suction cup was the key to success in tagging right whales. Despite this success, 50% of taggings failed to result in a good deployment (where

"good" is defined as 1 hour or more attachment time). There are two primary reasons for this: (1) some whales have poor skin condition with irregular features, and if the tag is attached on or adjacent to these irregularities, premature detachment by the suction cup is very likely (e.g., in Figure 1c, note skin lesions that would interfere with successful adhesion of the suction cup), and (2) right whales come in physical contact with one another frequently, particularly when aggregated in high-use areas; we experienced numerous premature detachments because the tag was knocked off by another animal during social interactions.

Table 1. Summary of at-sea activities in May, 2010 aboard NOAA Ship* Delaware II *on days that the rigid-hulled inflatable boat was launched to tag right whales. The table shows the number of whales tagged each day and the number of "good" deployments (defined as tag attachments of 1 hour or more).

Date	Right whales tagged	Good deployments
5/4/10	4	1
5/5/10	1	1
5/7/10	1	0
5/12/10	1	1
5/13/10	2	1
5/16/10	4	2
5/17/10	1	1
Total	14	7

The 2010 results dramatically illustrate the risk posed to right whales by ships. Half of the whales we studied were tagged inside the commercial shipping lanes that pass through the Great South Channel, and all of the whales spent the majority of their time in the upper 5-10 m of the water column (Figure 3). On one occasion, the captain of the *Delaware II* required us to suspend tracking activities because a cargo ship, the M/V *Mascot*, was passing within one mile of us and our tagged whale (Figure 4). This ship passed through a very large aggregation of right and sei whales, but at our request, did so at a reduced speed. The M/V *Mascot* is a 200-m long cargo ship with a draft of 11.6 m. The tagged whale spent nearly all of its time above this depth feeding on a shallow layer of copepods (Figure 3f). We were able to confirm that this tagged whale was feeding by observing its open mouth while it passed close by the RHIB.

The distribution of late-stage *Calanus finmarchicus*, primary prey of the right and sei whales in this region, was extremely patchy. We conducted concurrent zooplankton net sampling during the cruise, and net tows done in the same location within tens of minutes of one another would measure significantly different copepod abundances. We often observed very highly aggregated groups of whales feeding on patches only ~100-200 m in size. This is evident in our proximate sampling results with the optical plankton counter and video plankton recorder (Figure 3); high abundances of copepods were not always observed while tracking tagged whales despite our observations of active feeding behavior. When sampling very small patches in a highly advective environment, the chances of sampling the very patch upon which a whale is feeding are relatively low. The *Delaware II* sampled at each station along the whale's track 10-20 minutes after the whale left the station location, and during

the intervening period, the local currents would advect the small patch away from the station before the ship could sample it. In such cases, we expect high variability in copepod abundance along the whales' track, which is exactly what we observed in 2010 (Figure 3). Although we have observed patchiness in copepod distribution during surface feeding in the past, we have never observed patchiness to this degree. In contrast, when right whales are actively feeding on copepods at depth, this high level of patchiness is much less often observed.

IMPACT/APPLICATIONS

This work will directly help efforts to mitigate the effects of anthropogenic activities on baleen whales by characterizing where in the water column right whales feed and why the prey are organized as they are. Ultimately, our ability to predict or even forecast right whale distribution will hinge on a fundamental understanding of right whale foraging behavior and how that behavior varies with changes in copepod behavior and distribution.

RELATED PROJECTS

The project entitled "Physical and Biological Controls of Copepod Aggregation and Baleen Whale Distribution" (award number N000140811200, PIs Mark Baumgartner, Rubao Ji, Changsheng Chen) is closely linked to this project, as it is focusing on the physical and biological mechanisms that aggregate copepods in the Great South Channel and how those mechanisms influence baleen whale distribution. By understanding the local-scale distribution of prey and the resultant foraging behavior of right whales, we will be able to better characterize the response of whales to the aggregation processes elucidated in this related project.

Our observations of continuous feeding behavior for 2 weeks off of Cape Cod (Figure 2) was unexpected and has changed our view of aggregation mechanisms in the Great South Channel. The area in which the right whales were found is highly advective; a strong jet moves from northwest to southeast along the western flank of the Great South Channel. We conducted continuous sampling over a 48-hour period near surface drifting buoys on May 11-12, 2010, and we confirmed the presence of this strong jet and its ability to advect copepods out of the region where right whales were concentrated. These observations have led to the hypothesis that right whales remain within this jet because it brings a veritable flood of copepods from the central and western Gulf of Maine into the Great South Channel. The whales likely remain in areas where small-scale features or processes help to aggregate this large-scale flow of copepods into the extremely concentrated patches that right whales need to forage efficiently.

PUBLICATIONS

Our original proposal included time for analysis and publication the 2005-2009 tagging data after the 2009 field season. Because of our difficulties keeping tags attached to right whales in 2009, we decided to use the funds that were originally allocated for analysis and publication to support our participation in the NOAA NEFSC cruise aboard the NOAA Ship *Delaware II* in the spring of 2010. This allowed us to significantly increase our tagging sample size; however, it has precluded publication of our results. We will seek additional funds to support final analysis, synthesis, and publication of this study.

Figure 1. Methods used for the tagging study, including (a) R/V* Boo Radley*, our tagging boat, (b) approach on two humpback whales illustrating the use of the 9 m long tagging pole, (c) successful tagging of a North Atlantic right whale, and (d) deployment of the vertical profiling instrument package.

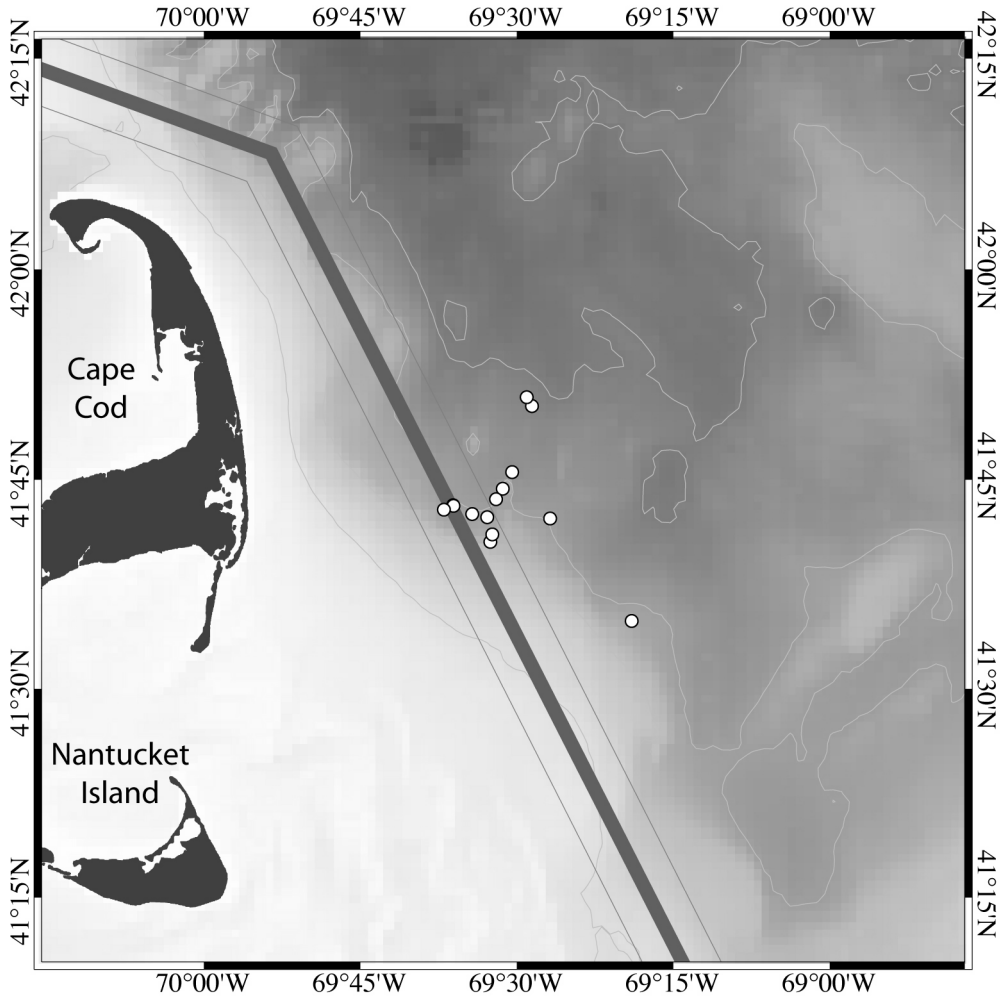

Figure 2. Initial tagging locations of 14 North Atlantic right whales in the northwestern Great South Channel. Whales were tagged in May 2010 during a cruise aboard the NOAA Ship* Delaware II. *The commercial shipping lanes that pass through the Great South Channel are shown.

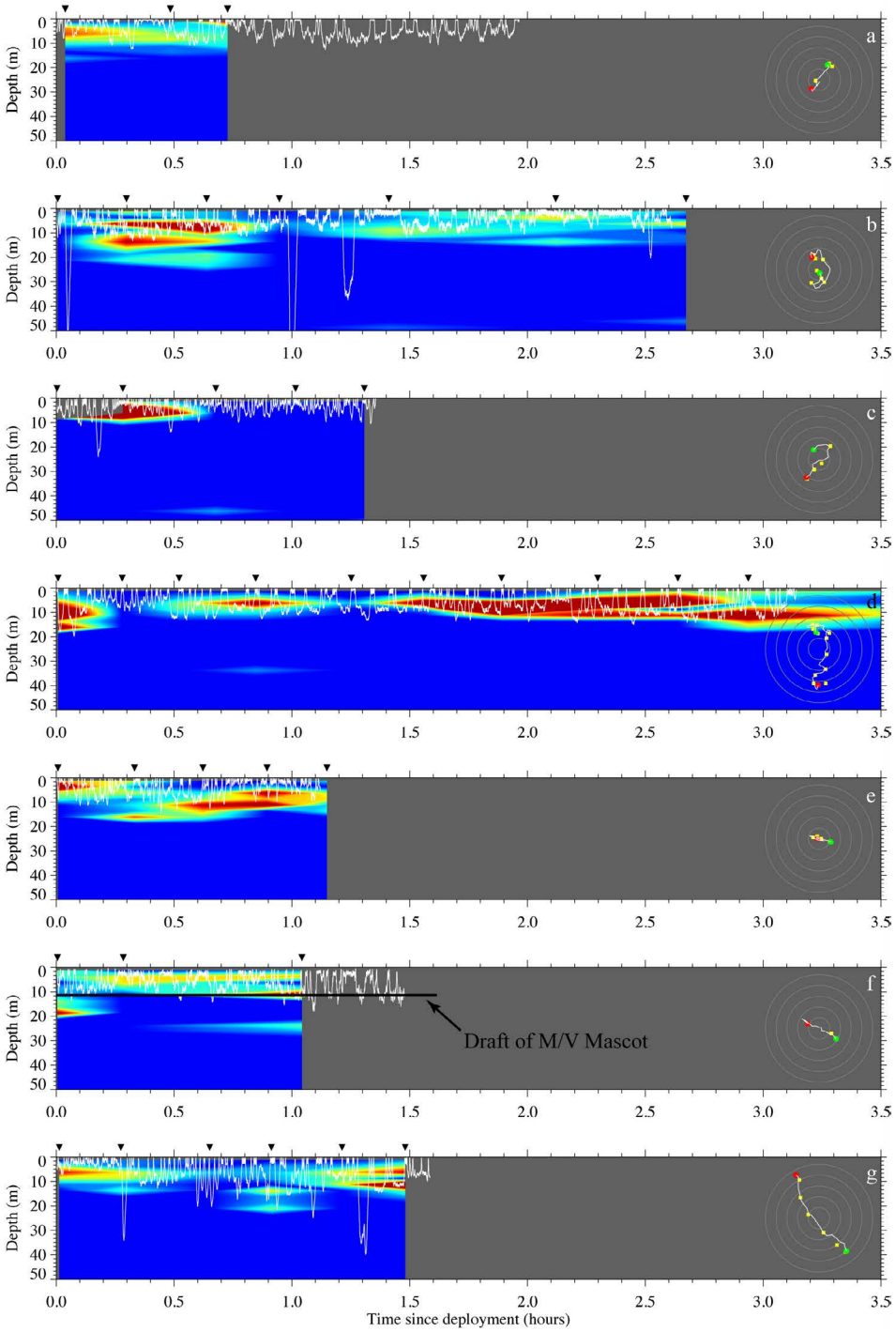

Figure 3. Dive behavior of 7 tagged whales for which the tag remained attached 1 hour or longer. Dive profile is shown as a white line and the distribution of late stage* Calanus finmarchicus *as measured by a video plankton recorder is shown as the color background (cool colors indicate low copepod abundance, warm colors indicate high abundance). The movements of the tagged whales are also shown in the inset map to the right (tagging location indicated with a green dot, tag detachment location indicated with a red dot, and the circles are shown in 1 km increments). Times and locations of vertical profiles shown as inverted triangles above the time series plot, and as yellow squares in the inset map. Water depths for each tagging event exceeded 125 m.

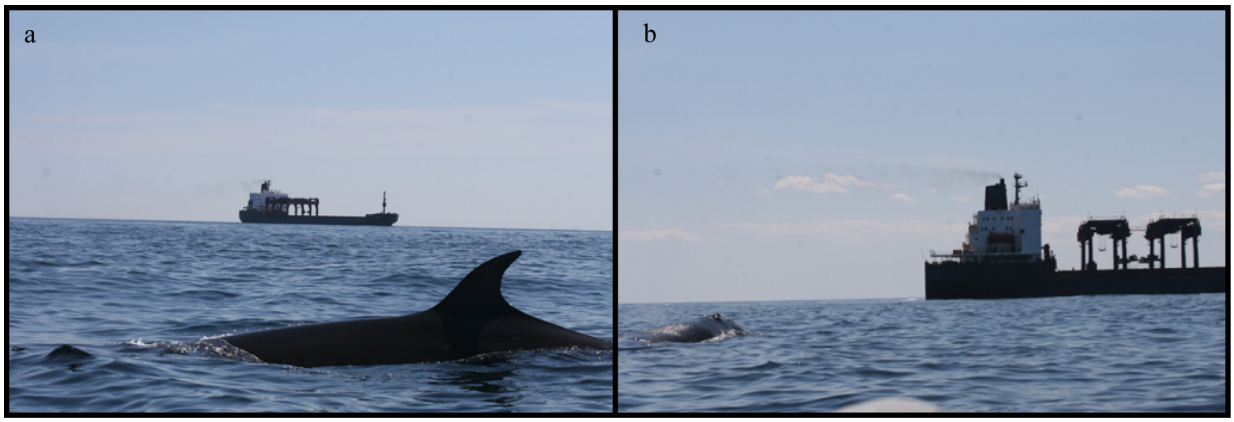

Figure 4. A (a) sei whale and (b) right whale surface within sight of the M/V* Mascot*, a 200-m long cargo ship transiting the Great South Channel shipping lanes on May 16, 2010. The draft of this vessel is 11.6 m, well below the surface layer of copepods upon which these whales were feeding.